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THE MAGNIFYING POWER OF MICROSCOPE- OBJECTIVES AND LENSES.

Three short Papers with Tables of Measurements.

By WALTER H. BULLOCH, F. R. M. S., Chicago, Ill.

I. Magnifying power of objectives measured from the posterior focus for parallel rays.

For several years considerable interest has been manifested in attempts to find the proper point from which to measure the magnifying power of objectives. Ten inches has generally been agreed upon as the standard of distance, but there has been considerable disagreement about the fixed point from which to measure that distance. The latest proposition is by Professor Abbe, most clearly set forth by Mr. Frank Crisp, in the *Jour. Roy. Mic. Soc.*, iii., p. 816, under the title "On 'Optical Tube-length'; an Unconsidered Element in the Theory of the Microscope." In this paper it is held that the ten inches used in estimating the magnifying power of an objective should be measured from the posterior focal plane of the objective. For my own part I think some other standard will have to be adopted, but I leave it for others to determine.

As few opticians care to give their formulæ to the public, in order to test the correctness of Abbe's proposition I have made a series of measurements to locate the position of the posterior focus for parallel rays entering the front of the objective, as suggested by Professor Abbe. The method adopted for determining the focus was to place the objective in the sub-stage of the microscope with the back toward the stage and use a low-power objective in the microscope to find the position of the image of a distant object

formed by the objective under investigation. In the case of high or low powers when the focus is within the combination, the back system makes some difference in locating the position of image. It may be slight, but still should be taken into the account.

I find much difference among the objectives of different makers; of those of about the same magnifying power, some have the posterior focus within the combination, others have it some distance behind the back system; for example, in the Spencer $\frac{2}{3}$ -inch of 36° the posterior focus was found to be .18 inch within the combination measuring from the back lens, in a Wale $\frac{2}{3}$ -inch of 30° , .34 inch behind the posterior combination.

How should objectives be named differing so much in magnifying power as the determinations below indicate? A Bausch & Lomb $\frac{1}{8}$ -inch of 180° , made about 1880, water or glycerine immersion, was examined. I could not find the focus for parallel rays; it is a four-system, with about four turns of the collar adjustment; it magnifies at "closed" 75.7 times, at three turns of collar 56 times. Likewise a Spencer $\frac{1}{8}$ -inch, dry or immersion, made about 1878, magnifies at "open" 88 times, at "closed" 130 times. A Gundlach $\frac{1}{8}$ -inch, made 1878, formerly owned by Col. J. J. Woodward, magnifies at "open" 130 times, at "closed" 150 times.

The accompanying Table No. 1, exhibits the determination of the position of the posterior focus of divers objectives, and the magnifying powers at ten inches from the ascertained focus.

II. *The magnifying power of double convex lenses.*

In the discussion on the adoption of a standard for eye-pieces at the Chicago meeting of the Society, it was generally assumed as correct that a 1-inch lens magnified 10 times at 10 inches from lens to micrometer: I expressed my doubts at the time. I have since examined the works on optics at my command, and cannot find evidence that any one of the authors have measured lenses to ascertain the facts. They appear to have been copying from one another, except in an article by the President, J. D. Cox, on page 134, "How to See with the Microscope," wherein a series of measurements are given at different distances, but they are measured from micrometer to micrometer. Mr. Cox gives the magnifying power of a 1-inch lens as 8 times. I make it $8\frac{1}{2}$.

It has been taken for granted that if a lens should magnify 10 times at 7 inches between micrometer and lens, it would magnify 20 times at 14 inches, without considering that when the focus is

TABLE NO. 1.

NO	MAKER OF OBJECTIVE.	Power of Objective.	Angle of Aperture.	Thickness of Combination.	Posterior Focus for Parallel rays from Front Sur- face.	Inside of outside of Combination.	Correction for Cover.	At what Cor- rection, if any.	Magnifying at 1 inch from Pos- terior Focus to Micrometer.	If with Ramsden Eye-Piece.
1	Spencer	$\frac{1}{10}$ H. do	125° B. A.	.35	.145	inside	yes	1.9 turns	107	Ramsd
2	do	$\frac{1}{10}$ H. do	113° B. A.	.31 closed	.11	inside	yes	open	96	do
3	Spencer	$\frac{1}{10}$ dry	immersion 180°	.37 open	.08	inside	yes	closed	111	do
4	do	do	do	.4 open	not found.	inside	yes, collar	open	92	do
5	Wales' Economic	do	do	.3 closed	.25	inside	yes	closed	88	do
6	Gundlach	$\frac{1}{10}$ H. do	water immers.	.27	.24	inside	no	open	130	do
7	do	$\frac{1}{10}$ H. do	do	.2	.15	inside	yes	open	110	do
8	Bausch & Lomb	$\frac{1}{8}$ H. do	140° dry	.47	.41	inside	yes	collar at 6 $\frac{1}{2}$	153	do
9	do	$\frac{1}{8}$ H. do	180° immersion	.5	not found.	inside	collar	0, closed	150	do
10	do	$\frac{1}{8}$ H. do	do	.58	not found.	inside	collar	3 $\frac{1}{2}$	60	do
11	Bausch & Lomb	$\frac{1}{8}$ H. do	116° dry	.44	.41	inside	yes	9 $\frac{1}{2}$	59	do
12	Zeiss	$\frac{1}{8}$ D. D. do	do	.45	.405	inside	yes	6 closed	56.6	do
13	do	$\frac{1}{8}$ D. D. do	do	.46	.40	inside	yes	3 turns	75.7	do
14	Gundlach	$\frac{1}{8}$ H. E. Series do	136° B. A.	.68	.53	inside	yes	20 closed	50	do
15	do	$\frac{1}{8}$ dry	135°	.47	.43	inside	yes	15 open	61.3	do
16	Bausch & Lomb	$\frac{1}{8}$ Student do	110°	.45	.41	inside	yes	10	61	do
17	Wales' Economic	$\frac{1}{8}$ C. C. do	90°	.43	.49	outside	no	10 $\frac{1}{2}$	53.3	do
18	Zeiss	$\frac{1}{4}$ C. C. do	115°	.42	.39	inside	yes	open.	53.8	do
19	Spencer	$\frac{1}{4}$ dry	do	.5	.54	outside	yes	9 $\frac{1}{2}$ closed	55	do
20	do	$\frac{1}{4}$ do	do	.45	.51	outside	yes	.....	54.3	do
21	Bausch & Lomb	$\frac{1}{10}$ H. do	98°	.29	.15	inside	no	.....	63.7	do
22	Wales	$\frac{1}{10}$ H. do	30°	.69	.94	outside	yes	16	46	do
23	Grunow	$\frac{1}{10}$ H. do	36°	.515	.85	outside	no	open	48.8	do
24	Spencer	1 inch	40°	.....	.18 inside of back	inside	no	closed	50.4	do
25	Bausch & Lomb	1 inch	36°	.....	.02 inside of back	inside	no	open	26.4	do
26	Spencer	2 inch	do	.....	.04 inside of back	inside	no	closed	21.7	do
27	Grunow	1 $\frac{1}{2}$ inch	do	.....	.67	outside	no	.....	16	do
28	Zeiss	$\frac{3}{8}$ A. A. do	20°	.65	.123	outside	no	.....	16.25	do
29	do	$\frac{3}{8}$ A. A. do	do	.113	.84	inside	no	.....	19	do
30	Zeiss	1, 2 & 23mm. a*	do	2.05	8.53	outside	collar	.....	11.1	do
31	do	do	do	2.15	7.8	outside	collar	.....	10.5	do
32	do	do	do	2.3	7.3	outside	collar	.....	5.36	do
33	Gundlach	$\frac{3}{8}$ inch	do	3.55	3.	inside	slide collar	.....	9.63	do
34	do	do	do	2.58	2.81	outside	slide	.....	14	Ramsd
35	do	do	do	2.03	2.81	outside	closed	closed	6	do

TABLE NO. 1.

	Thickness of Combination.	Posterior Focus for Parallel Rays from Front Sur- face.	Inside or outside of Combination.	Correction for Cover.	At what Cor- rection, if any.	Magnifying at 10 inch from Pos- terior Focus to Micrometer.	If with Ramsden Eye-Piece.	If Measured with the Diaphragm.	Correction for Collar.	Magnifying at 12 1/2 inch.	Correction for Collar.	Magnifying at 15 inch.
A.	.35	.145	inside	yes	1.9 turns	107	Ramsden	.....	closed	137	open	140
.....	.....	.....	.....	yes	open	96	do	.....	1.9 turns	133	1.9 turns	155
.....	.31 closed	.11	inside	yes	closed	111	do	.....	.....	.....	.....	.....
.....	.37 open	.08	inside	yes	open	92	do	.....	.....	.....	.....	.....
80	.4 open	not found.	.....	yes, collar	open	88	do	.....	.....	.....	.....	.....
.....	.3 closed	.25	inside	yes	closed	130	do	.....	.....	.....	.....	.....
.....	.27	.24	inside	no	.....	110	do	.....	.....	.....	.....	.....
rs.	.2	.15	inside	yes	open	130	do	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	collar at 6 1/4	153	do	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	o, closed	150	do	.....	.....	.....	.....	.....
.....	.47	.41	inside	yes	3 1/2	60	do	.....	3 1/2 div.	70.4	.....	.....
.....	.....	.....	.....	.....	o	59	do	.....	o	70.6	.....	.....
.....	.....	.....	.....	.....	9 1/2	56.6	do	.....	9 1/2	76	.....	.....
sion	.5	not found.	inside	collar	6 closed	75.7	do	.....	.....	.....	.....	.....
.....	.58	.....	.....	collar	3 turns	50	do	.....	.....	.....	.....	.....
.....	.44	.41	inside	yes	20 closed	63.3	do	.....	20	80	20 div.	92.2
.....	.45	.405	inside	yes	15 open	61.3	do	.....	15	78	15	91
.....	.46	.40	inside	yes	10	61	do	.....	10	77	10	90
A.	.68	.53	inside	yes	10 1/2	53.3	do	.....	10 1/2	66.6	.....	.....
.....	.47	.43	inside	yes	open.	53.8	do	.....	.....	.....	.....	.....
.....	.45	.41	inside	yes	9 1/2 closed	55	do	.....	.....	.....	.....	.....
.....	.43	.49	outside	no	.....	54.3	do	.....	.....	.....	.....	.....
.....	.41	.39	inside	no	.....	63.7	do	.....	.....	.....	.....	.....
.....	.42	.32	inside	yes	16	46	do	.....	16	60	16	68.5
.....	.5	.54	outside	yes	open	48.8	do	.....	.....	.....	.....	.....
.....	.45	.51	outside	yes	closed	50.4	do	.....	.....	.....	.....	.....
.....	.29	.15	inside	no	.....	26.4	do	.....	.....	33.8	.....	40
.....	.....	.02	outside	yes	closed	21.7	diaphragm	.....	.....	.....	.....	.....
.....	.69	.94	outside	no	.....	16	do	.....	.....	20	.....	23.33
.....	.515	.85	outside	no	.....	16.25	do	.....	.....	.....	.....	.....
.....	.....	.18 inside of back	inside	no	.....	19	do	.....	.....	.....	.....	.....
.....	.....	.02 inside of back	inside	no	.....	11.1	do	.....	.....	13.9	.....	16.6
.....	.....	.04 inside of back	inside	no	.....	10.5	do	.....	.....	.....	.....	.....
.....	.....	.67	outside	no	.....	5.36	.....	.....	.....	6.66	.....	8
.....	.65	.123	outside	.....	.....	9.63	.....	.....	.....	.....	.....	.....
.....	.113	.84	inside	no	.....	14	Ramsden	.....	.....	17.6	.....	20
.....	2.05	8.53	outside	collar	closed	6	do	.....	.....	.....	.....	.....
.....	2.15	7.8	outside	collar	at No. 5	5	do	.....	.....	.....	.....	.....
.....	2.3	7.3	outside	collar	open	4	do	.....	.....	.....	.....	.....
.....	3.55	3.	inside	slide collar	open	3 1/2	do	.....	.....	.....	.....	.....
.....	2.58	2.81	outside	slide	1/2 open	3.8	do	.....	.....	.....	.....	.....
.....	2.03	2.81	outside	closed	closed	4 1/2	.....	.....	.....	.....	.....	.....

lengthened at one end, the conjugate focus at the other is shortened. From my measurements, a 1-inch lens, the focal length generally adopted as the standard of magnifying power, I find magnifies only 9.09 times, which is ten per cent. less than the theoretical power.

TABLE NO. II.

MAGNIFYING POWER OF DOUBLE CONVEX LENSES MEASURING FROM THE EDGE OF LENS 10'' TO DIAPHRAGM .25 DIAMETER AND MICROMETER ON STAGE, DIVIDED TO 1-1000.

FOCUS OF EACH LENS	DISTANCE BETWEEN LENSES AND MICROMETER—DIAPHRAGM.—					
	7 INCHES.	14 INCHES.	8 INCHES.	10 INCHES.	12½ INCHES.	15 INCHES.
	Times.	Times.	Times.	Times.	Times.	Times.
.3	21.75	45	25	31.25	41.66	50
.55	11.11	23.81	12.05	16.66	20.83	25
.82	7.81	16.66	8.92	11.36	14.7	19
.99	6.1	13.15	7.14	9.09	11.9	15.15
1.73	3	7.14	3.58	4.71	6.25	7.52
2.05	2.38	5.81	2.9	3.69	5.81	6.44

III. *The position of the Wollaston Camera in measuring objects.*

As there is some disagreement among microscopists as to whether it makes any difference in the measurement of objects by means of the Wollaston Camera Lucida, if the distance is the same between the table and camera, and the camera and the object on the stage, I submit the following measurements in Table III., for your consideration. I cannot see that it makes any difference whether the distance between table and camera is changed, or with the draw-tube the distance between camera and object. Each measurement is made from posterior focus of objective to diaphragm of eye-piece.

TABLE NO. III.

⅔ GRUNOW.			⅔ SPENCER.		
Conjugate focus from Objective to Eye-piece.	Distance from edge of Camera Lucida to table.	Magnifying Power.	Conjugate focus from Objective to Eye-piece.	Distance from edge of Camera to table.	Magnifying Power.
Inches.	Inches.	Times.	Inches.	Inches.	Times.
10	10	94	10	10	79
10	13 ³ / ₈	125	10	15	116
13 ³ / ₈	10	125	15	10	117
13 ³ / ₈	10	121	15	15	172
10	16 ¹ / ₈	156			
13 ³ / ₈	16 ¹ / ₈	200			